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Climate change, demographic pressures and global sustainability

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ABSTRACT

This article emphasizes the need for broader approaches for formulating policies for mitigating the effects of climate change especially in the contexts of agricultural decisions, and population health and migration. Constraints imposed by rapid population growth in developing countries for achievement of Sustainable Development Goals are discussed and evidence is presented on "unwanted" fertility from India. Second, comparisons are made for India during 2002–2016 for average well depths in 495 districts and terrestrial water storage anomalies assessed via GRACE satellites for 274 $1^\circ \times 1^\circ$ grids using estimated parameters from dynamic random effects models. Lastly, migration patterns especially of the highly educated from 39 sending countries to OECD countries during 2000–2010 are analyzed using dynamic random effects models and total fertility rates were significantly associated with higher migration rates for the highly educated. Implications of the empirical evidence for enhancing global sustainability are discussed.

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1. Introduction

With recent upward trends in global temperatures and sea levels, many countries are experiencing higher rates of evapotranspiration, groundwater depletion, water salinity, and loss of habitats (Intergovernmental Panel on Climate Change, 2014; Rockstrom et al., 2009; Mc Neill and Engleke, 2016). Moreover, increases in living standards often entail higher consumption of animal products (Bhargava, 2015) that require greater natural resources. While the United Nations (2015) has recognized some of these issues in the 17 Sustainable Development Goals, the recommendations seem somewhat simplistic since they fail to recognize the inter-connections between the goals and the pressures exerted by population growth. Rapid population growth in many developing countries is hampering the attainment of sub-goals such as "ending hunger and food insecurity", "improving education quality", "providing adequate sanitation", and "achieving productive employment". Thus, for example, high birth orders in India were significantly negatively associated with children's heights and weights (Bhargava et al., 2011) and with the uptake of vaccinations (Bhargava et al., 2014). For the formulation of evidence-based policies, it is important to identify the salient demographic and socioeconomic factors. In addition, remote sensing information on environmental variables such as terrestrial water storage anomalies (Tapley et al., 2004) and soil moisture (Entekhabi et al., 2010) can enhance agricultural decision making and productivity. This article emphasizes the importance of setting realistic policy goals and outlines the steps through which the goals relating to agricultural decisions, and population health and migration patterns might be achieved in the wake of climate change.

2. Population growth, demand for food and sustainable development

The implications of rapid population growth for food production were underscored by Malthus in 1798 (Malthus, 1985). However, cultivation of new lands and improvements in agricultural technologies have afforded adequate supplies of dietary energy for most populations. More recently, food fortification programs and improved vegetables containing higher quantities of

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micronutrients are improving diet quality in developing countries (International Food Policy Research Institute, 2016). However, environmental pressures such as depletion of groundwater and land degradation are gradual and their assessment requires a longer time frame. While Hardin (1968) argued that "It is a mistake to think that we can control the breeding of mankind in the long run with an appeal to conscience", declines in child mortality and easier access to healthcare services in remote areas of developing countries have motivated many couples to limit their family size and educate children (Bhargava, 2008). Small family size is helpful for creating a skilled labor force, as has been the experience of countries such as Japan, South Korea and China after the Second World War.

For illustrating the magnitudes of mistimed and unwanted births, Fig. 1 reports total fertility rates and "unwanted" fertility (Bongaarts, 1990) in the populous Indian states of Bihar, Rajasthan, Madhya Pradesh, and Uttar Pradesh using data from National Family Health Surveys 3 and 4 conducted, respectively, in 2005-06 and 2015-16 covering over 125,000 women (International Institute for Population Sciences, 2007, 2017). While "unintended" pregnancies have been estimated under certain assumptions for countries (Bearak et al., 2018), unwanted fertility assessed via demographic survey items provide direct and disaggregated evidence (Bhargava, 2003). The percentages of children in the four states who were regarded as unwanted by their mothers in 2005-06 were 40, 31, 32, and 39, respectively. Corresponding estimates for 2015-16 were 26, 25, 22, and 22, respectively. It is astonishing that despite impressive economic growth in India, about a quarter of children in the largest states were unwanted. Most of such births occurred in rural and remote areas with limited access to healthcare and family planning services after the couples had achieved their fertility goals.

Further, while poor couples often struggle to educate their children, unwanted births exert pressures on the already weak educational infrastructures. Small family size is critical for children's nutritional status, cognitive development, and future supply of skilled labor (Bhargava, 2008). For example, evidence from Kenya showed that children born at high birth orders had significantly lower head circumference (Bhargava, 2000) that is an indicator of brain mass (Dobbings and Sands, 1978). Such aspects are especially important in the wake of climate change that will reduce habitable areas due to rising sea levels. It seems apt to abandon the anachronistic notion of the benefits of a "population dividend" for developing countries that often stems from a failure of healthcare services (e.g. Cleland, 1996). In fact, population increases of over 33 million during 1980–2010 in six Indian states (Bihar, Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh and West Bengal) were significantly associated with greater groundwater depletion (Bhargava, 2018).

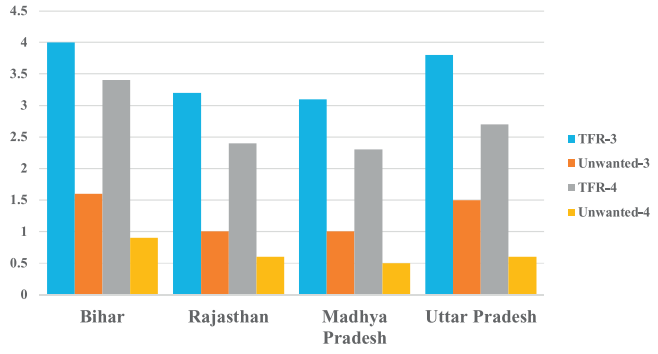

Fig. 1. Total Fertility Rates and Unwanted Fertility from the National Family Health Survey 3 and 4 in India.

Lastly, from the related nutritional and health viewpoints, higher protein and micronutrient intakes are beneficial for individuals' health though the effects may be diluted or even reversed for populations consuming higher than necessary quantities of dietary energy. Recent increases in obesity in developed countries and among affluent groups in developing countries have increased the prevalence of chronic diseases (Bhargava, 2015). Moreover, large body sizes increase individuals' energy requirements and, in turn, the demand for energy-dense foods including animal products that require greater natural resources. Such factors create pressures on the environment and the problems are compounded by agricultural subsidies in developed countries (Elinder, 2005). Thus, there is a need for correcting global imbalances in demand and supply of agricultural products due to population growth, increases in obesity, and wasteful agricultural subsidies. A systematic approach for policy formulation would reduce unwanted fertility in developing countries, impose taxes on processed and unhealthy foods, and reduce agricultural subsidies in developed countries. For example, the 1 peso per liter excise tax on sugar sweetened beverages in Mexico from January 2014 led to a 7.3% decline in per capita sales and a 5.2% increase in plain water sales during 2014-15 (Colchero et al., 2016). While this tax by itself cannot stem obesity and diabetes epidemics, policies promoting healthful diets should have a nutrition component for enhancing their long-term efficacy.

3. Environmental factors, remote sensing information and food production

Maintaining the global supplies of nutritious foods should be a primary objective of food policies (De Fries et al., 2015). While lower population growth can reduce the demand for food from what it might otherwise be, food production depends on environmental variables such as temperatures, rainfall, soil quality and moisture, and agricultural technologies. With increases in temperatures and greater rainfall variability due to climate change, it is important to ensure that resources are efficiently utilized. For example, while it may be lucrative for farmers in developing countries to grow rice in semi-arid regions using groundwater, governments should provide incentives for cultivating alternative crops and withdraw electricity subsidies in areas with rapid depletion (Bhargava, 2018). By contrast, rice cultivation in flooded fields is efficient since the opportunity costs of water use are low. In addition, the time frame over which the impact of agricultural technologies is assessed is important. For example, while drip technologies can reduce water use in the short and medium terms, it is important to maintain water runoff for re-charging aquifers (Birkenholtz, 2017). Simultaneous increases in population and living standards can hamper the long-term production of crops that heavily rely on groundwater.

Further, it is important to monitor groundwater depths in various regions and plant crops according to their transpiration efficiency (Food and Agriculture Organization, 1992). While monitoring groundwater levels can be expensive, information from orbiting satellites can provide useful data on terrestrial water storage anomalies and soil moisture. For example, in situ groundwater depths are measured in India for over 30,000 wells at quarterly intervals (Central Ground Water Board, 2018) though, due to resource constraints and logistics, the depths are assessed at less frequent intervals. By contrast, GRACE satellites (Tapley et al., 2004) provide information on terrestrial water storage anomalies at monthly intervals at resolutions of 200,000 square kilometers on the basis of differential gravitational acceleration and by employing spherical harmonic functions (Torge, 2001). Note that deviations from time means over certain periods ("anomalies") are reported and higher values reflect greater "aquifer thicknesses".

While coarse resolutions for 200,000 square kilometers may seem inadequate for agricultural decision making, recently launched SMAP satellites (Entekhabi et al., 2010) assess moisture in the top 5 cm of soil at 9 or 36 square kilometer resolutions.

Figs. 2 and 3 plot, respectively, sample means and coefficients of variations (standard deviations expressed in terms of the means) in India during 2002–2016 for average well depths in 495 districts and terrestrial water storage anomalies assessed via GRACE satellites for 274 $1^\circ \times 1^\circ$ grids. There was a gradual upward trend in average well depths in Fig. 2 and a paired *t*-test showed statistically significant ($P < 0.05$) increase between 2002 and 2016. Similarly, Fig. 3 showed that aquifer thicknesses significantly declined between 2002 and 2016. Note, however, that standard deviations of terrestrial water storage anomalies were considerably larger than those for well depths. In fact, coefficients of variations for well depths in Fig. 2 were in the tight interval [0.666, 0.872]. By contrast, coefficients of variations for the GRACE satellite data were between [-2.277, 6.358] showing much greater spread. Because these statistics do not account for between district and grid variations, estimated parameters from dynamic random effects models can provide further insights.

Table 1 reports the maximum likelihood estimates of dynamic random effects models for well depths and terrestrial water storage anomalies, respectively, for 495 districts and 274 grids in India. Specification 1 is the general formulation for the errors, while Specification 2 decomposed the errors in a simple random effects fashion (Bhargava and Sargan, 1983). For illustration, the dynamic model for average well depths is given by:

$$\ln(\text{Average well depth})_{it} = a_0 + a_1(\text{Time period 3})_{it} + a_2(\text{Time period 4})_{it} + a_3(\text{Time period 5})_{it} + a_4(\text{Time period 6})_{it} + a_5(\text{Time period 7})_{it} + a_6(\text{Time period 8})_{it} + a_7(\text{Time period 9})_{it} + a_8(\text{Time period 10})_{it} + a_9(\text{Time period 11})_{it} + a_{10}(\text{Time period 12})_{it} + a_{11}(\text{Time period 13})_{it} + a_{12}(\text{Time period 14})_{it} + a_{13}(\text{Time period 15})_{it} + a_{14}\ln(\text{Average well depth})_{it-1} + u_{it} \quad (i = 1, \ldots, 495;\ t = 2, \ldots, 15). \quad (1)$$

In the general model in Specification 1 in Table 1, u_{it} were assumed to be drawings from a multivariate normal distribution with 15×15 variance covariance matrix Ω. By contrast, in Specification 2, Ω was assumed to be the matrix corresponding to the simple random effects decomposition:

$$u_{it} = \delta_i + v_{it}, \quad (2)$$

where δ_i are district-specific random effects that were distributed with mean zero and (between) variance σ_δ^2, and v_{it} were randomly distributed variables with (within) variance σ^2. A likelihood ratio test can be applied for testing the validity of the decomposition in Eq. (2). For large numbers of districts observed in 15 time periods, the likelihood ratio statistic was distributed as a Chi-square variable with 116 degrees of freedom. The model in Eq. (1) was also estimated by maximum likelihood for terrestrial water storage anomalies and the results are presented in Table 1.

The estimated coefficients of the indicator variables for time periods in Table 1 confirmed an increase in well depths and reductions in terrestrial water storage anomalies especially for the recent years 2015 and 2016. Moreover, within variances were considerably larger for terrestrial water storage anomalies and so were the coefficients of lagged dependent variables indicating higher degree of persistence. The likelihood ratio tests rejected the simple random effects decompositions in Specification 2 for average well depths and for terrestrial water storage anomalies, presumably due to heteroscedasticity and/or serial correlation over time in the errors. Overall, these results underscored the importance of compiling data on well depths and the need for increasing the resolutions of remote sensing data for making agricultural decisions. Further information on agricultural production and population increases at the district and grid levels can facilitate better management of risks in the wake of climate change.

4. Climate mitigation and adaptation, migration and fertility

The rising sea levels and erratic rainfall patterns are likely to increase migration within countries as well as emigration abroad. For example, internal migration in China has enabled over 150 million workers from rural areas to be employed in the Special Economic Zones (Bhargava and Tan, 2018). While remittances sent by migrants are helpful for economic development (World Bank, 2018), intensive industrial activity has increased environmental degradation and the prevalence of Chronic Obstructive Pulmonary Diseases (Gao and Prasad, 2013). By contrast, emigration from Bangladesh has increased due to persistent water inside houses (Ishaque et al., 2011) to neighboring countries such as India where the migrants often face discrimination. It is important to understand the complex inter-relationships between migration, health, fertility, education, labor productivity, and environmental pressures for the formulation of evidence-based policies.

First, internal migration from rural to urban areas especially in developing countries is likely to be easier for healthy individuals though the living conditions such as poor sanitation in congested urban areas may ultimately be detrimental for health. The evidence from China suggests that men with lower blood pressures were able to spend greater lengths of time working away from home (Bhargava and Tan, 2018). Second, migration to urban slums in developing countries can create the misleading impression that population densities in rural areas are low and that the overall population density is sustainable. However, habitat loss, groundwater depletion, and low agricultural productivity, biodiversity and forest cover are better indicators of environmental conditions.

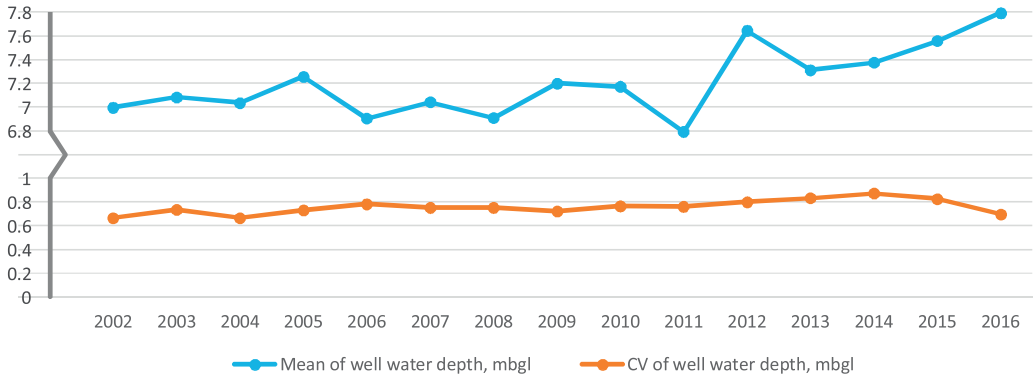

Fig. 2. Means and coefficients of variations of well water depths (meters below ground level) in India.2002–2016.

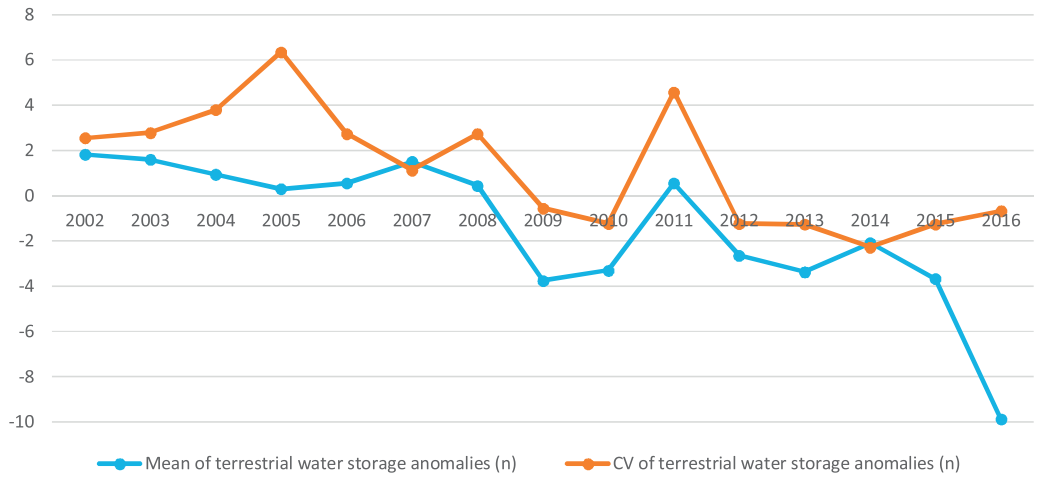

Fig. 3. Means and coefficients of variations of terrestrial water storage anomalies in India, 2002- 2016.

Table 1
Maximum likelihood estimates of dynamic random effects models for India using 15 annual observations in 2002–2016 for average well water depths in 495 districts and terrestrial water storage anomalies in 274 1° × 1° grids [1].

Dependent variable:	ln(Well water depth), mbgl				Terrestrial water storage anomalies, n			
Model:	Specification 1[2]		Specification 2[2]		Specification 1[2]		Specification 2[2]	
Explanatory variables:	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE
Constant	0.965	0.017	0.664	0.018	0.113	0.113	0.101	1.249
Time period 3, 0-1	−0.006	0.012	−0.006*	0.010	−0.480*	0.163	−0.480*	0.157
Time period 4, 0-1	0.020	0.011	0.021*	0.001	−0.569*	0.188	−0.567*	0.157
Time period 5, 0-1	−0.032*	0.011	−0.035*	0.010	0.189	0.237	0.192	0.161
Time period 6, 0-1	0.002	0.011	0.005	0.010	0.944*	0.152	0.946*	0.154
Time period 7, 0-1	−0.030*	0.011	−0.029*	0.010	−0.895*	0.158	−0.894*	0.159
Time period 8, 0-1	0.035*	0.009	0.040*	0.010	−4.230*	0.179	−4.226*	0.159
Time period 9, 0-1	0.002	0.012	−0.002	0.010	0.352	0.294	−0.340*	0.165
Time period 10, 0-1	−0.048*	0.001	−0.050*	0.010	3.122*	0.124	3.132*	0.143
Time period 11, 0-1	0.096*	0.011	0.103*	0.010	−3.204*	0.136	−3.200*	0.159
Time period 12, 0-1	−0.023*	0.011	−0.036*	0.010	−1.317*	0.201	−1.308*	0.164
Time period 13, 0-1	0.006	0.011	0.004	0.010	0.544*	0.203	0.555*	0.159
Time period 14, 0-1	0.037*	0.013	0.035*	0.010	−2.094*	0.200	−2.085*	0.168
Time period 15, 0-1	0.091*	0.017	0.083*	0.010	−6.984*	0.354	−6.973*	0.158
Lagged dep. var.	0.459*	0.007	0.628*	0.010	0.815*	0.013	0.817*	0.010
Between/within var.	–		1.558*	0.130	–		0.150*	0.019
Within variance	–		0.0247	–	–		3.9407	–
2xlog-likelihood fn.	26663.5		25560.1		9376.6		−5717.5	
Chi-square test random effects decomposition [3]			1102.4*				15,094.1*	

[1] Values are slope coefficients and standard errors.
[2] Specification 1 is the general model and Specification 2 is a special case with random effects decomposition.
[3] Chi-squared statistics for testing the simple random effects decomposition is distributed with 116 degrees of freedom.
* $P < 0.05$.

Third, for analyzing the role of demographic and economic factors affecting migration to OECD countries, empirical models were estimated for total migration, migration of the highly educated and migration rates for the highly educated from 39 sending countries in 2000, 2005, and 2010 (Organization of Economic Cooperation and Development, 2018). The model for total migration is given by:

$$\ln(\text{Total migration})_{it} = b_0 + b_1(\text{Average secondary enrollment})_i + b_2(\text{Total fertility rate})_{it} + b_3 \ln(\text{Gross Domestic Product})_{it} + b_4 \ln(\text{Total population})_{it} + b_5 \ln(\text{Total migration})_{it-1} + u_{2it} \quad (i = 1, \ldots, 39;\ t = 2,3) \quad (3)$$

Note that the logarithmic transformations of GDP per capita and total population variables are likely to reduce nonlinearities in the empirical relationships. In addition, enlarged version of the models in Eq. (3) were estimated with squared logarithms of GDP per capita and total population included as explanatory variables. Also, the definition of migrants in censuses and population registers in OECD countries consists primarily of legal residents that include former asylum seekers and refugees (Organization of Economic Cooperation and Development, 2018). Lastly, the data from World Development Indicators (2018) on variables such as total fertility rates, Gross Domestic Product per capita, and secondary school enrollment rates were merged with the OECD migration data.

Table 2 presents the maximum likelihood estimates of models for total migration, migration of the highly educated, and migration rates for the highly educated from sending countries to OECD countries; the sending countries are listed in Table 2. In the model for total migration and migration of the highly educated, total fertility rate was estimated with negative and significant coefficients indicating that higher fertility rates were associated with lower migration to OECD countries. By contrast, the estimated coefficient of total fertility rate in the model for migration rates for highly educated was *positive* and significant indicating to some

Table 2
Maximum likelihood estimates of dynamic random effects models for total and highly educated migration patterns from 39 sending countries to OECD countries in 2000, 2005 and 2010[1,2].

Dependent variable:	ln (Total migration), 1000's		ln (Highly educated migration), 1000's		ln (Highly educated migration rate),%	
Explanatory variables:	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	0.625	1.498	−4.952	1.576	−1.764	1.262
ln (Secondary school enrollment),% gross	0.088	0.205	0.624*	0.154	0.646*	0.174
Total fertility rate, n	−0.188*	0.086	−0.143*	0.071	0.173*	0.053
ln (Gross Domestic Product), per capita 2005 PPP	0.007	0.102	−0.008	0.054	−0.155*	0.069
ln (Total population), n	0.164*	0.051	0.413*	0.047	0.148*	0.034
Lagged dependent variable	0.498*	0.144	0.178*	0.050	0.204*	0.099
Between/within variance	6.035	4.574	19.596*	4.942	20.116*	6.164
Within variance	0.0165		0.0095		0.0050	
2 x log-likelihood function	334.88		378.95		452.33	

[1] Values are slope coefficients and standard errors estimated using data on migration from 39 sending countries to OECD countries in 2000, 2005 and 2010.
[2] The 39 countries were: Albania, Algeria, Argentina, Bangladesh, Brazil, Cameroon, China, Colombia, Democratic Republic of Congo, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Ghana, Guatemala, Guyana, Honduras, India, Iran, Iraq, Kenya, Mauritius, Morocco, Pakistan, Peru, Philippines, Romania, Senegal, South Africa, Sri Lanka, Sudan, Thailand, Tonga, Tunisia, Uganda, Venezuela, and Vietnam.
* $P < 0.05$.

degree "brain drain" to OECD countries. In countries with high fertility rates, it is often difficult to provide primary, secondary and tertiary education for children and the coefficient of total fertility rate underscore the importance of reducing unwanted fertility for retaining high skilled labor.

Further, the coefficient of GDP per capita was significant only in the model for migration rates for the highly educated. By contrast, coefficients of total population were positive and significant in all models indicating the importance of reducing population pressures for migration. Lastly, coefficients of squared logarithms of GDP per capita and total population variables were significant in the enlarged model for total migration though that was not the case in the model for migration rates for the highly educated, presumably due to the small sample sizes available. However, the main findings such as the effects of total fertility rates on migration patterns from log-linear models in Table 2 were robust to changes in model specification. Overall, small family sizes enables higher proportions of children to complete their education, and harmonizing migration patterns taking into account fertility differentials in developing and OECD countries can benefit the sending as well as destination countries.

5. Conclusion

In the wake of climate change, it is important to formulate mitigation and adaptation policies in a broad framework encompassing scientific, environmental, demographic and socioeconomic aspects. Such approaches entail compilation of longitudinal data on natural resources, environmental and health indicators, and economic and demographic variables for enhancing global sustainability. First, it would be helpful to emphasize the benefits of healthcare and family planning services for enabling couples to achieve their desired family size by reducing unwanted fertility. Moreover, education of girls and greater employment opportunities for women can lower the desired family size. The United Nations Sustainable Development Goals are unlikely to be met by 2030 because the ambitious objectives cannot be tackled using the existing natural and human resources. For example, it is important to recognize that attainment of the Sustainable Development Goal 4 emphasizing "equitable quality education and promote lifelong learning opportunities" critically depends on adequate resources for education that are in turn facilitated by small family size; it is essential to outline how the goals might be operationalized.

Second, with advances in satellite technologies, evidence-based policies can be formulated for agricultural decisions using remote sensing information with finer image resolutions. Moreover, it is counter-productive for developed countries to provide agricultural subsidies that create market distortions and may be exacerbating the obesity and chronic disease epidemics via low food prices. In fact, it would be efficacious to provide subsidies for generating renewal energy rather than subsidizing large agribusiness that promote consumption of unhealthy and processed foods. Finally, in view of differential fertility rates in developing and developed countries, it is important to harmonize international migration patterns for low, medium, and high skilled labor for maintaining global economic productivity and well-being. The analyses of migration patterns to OECD countries showed the importance of reducing fertility rates in sending countries for retaining skilled labor that is critical for economic development. While atmospheric concentrations of carbon dioxide might have crossed a "critical threshold" (Rockstrom et al., 2009), analyses of emissions of greenhouse gases such as methane and nitrous oxide using elaborate data sets such as FAOSTAT (Food and Agriculture Organization, 2019) can facilitate policy formulation. Overall, public policies need to take into account the existing realities such as population levels in countries and the prescriptions should be acceptable from broader normative and economic standpoints.

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